SULFUR RECOVERY IN THE MANUFACTURE OF PIPELINE GAS FROM COAL

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U. S. SULFUR NEEDS

U. S. sulfur consumption is growing at an increasingly rapid rate. Annual consumption increased from 5.5 million long tons in the middle 1950's to 7.8 million tons in 1965,[15] an annual increase of 3.6%. Consumption in 1967 was 9.3 million long tons, 8.3 million tons being provided by U. S. production, the rest from stocks and Canadian sour gas and refinery recovery.[2,13] The annual average increase from 1965 to 1967 was 9%/yr.

Projections for 1970 and 1975, respectively, indicate U. S. consumption of 11 and 17 million long tons/yr.[13,15] Market projections also allow for 2.7 and 5.0 million tons/yr for export in addition to the above. This is a big increase over the 1.3 million tons exported in 1967. If the exports are included, U. S. sulfur needs would increase 100% over 1967 figures by 1975.[13]

A large part of this increase may be met by desulfurization of fuels. It is estimated that about 12 million tons of sulfur is emitted yearly to the atmosphere in the U. S. by fuel combustion processes.[6,14] This exceeds the current U. S. sulfur consumption. Not all of this is readily recoverable, however.

The public concern over air pollution, resulting in the need for desulfurization of fuels and/or flue gases; the availability of desulfurization processes; and the expanding need for sulfur will combine to make desulfurization a reality. Currently, about 70% of U. S. sulfur supplies are met by Frasch sulfur; over 80% of U. S. production is by this method. Future expansion will require other sources.

SULFUR IN U. S. COALS

In less than a generation we will have to meet part of the demand for liquid and gaseous fuels by conversion of coal and oil shale. This paper is limited to the recovery of sulfur during the conversion of coal to pipeline-quality gas by hydrogenation. In the manufacture of pipeline gas from coal most of the sulfur is also gasified. Regardless of whether the coal is burned conventionally or converted to gas, its sulfur content is of great importance.

The rank, sulfur content, and sulfur type of the coal reserves of the United States have been published by the U. S. Bureau of Mines.[3] Sulfur levels range from 0.2% or less to 7% by weight on a dry basis.[10] Of the total estimated U. S. coal reserves of all ranks, as of January 1, 1965, 65% is low-sulfur coal (1.0% or less). This 65% includes 91% of the lignites, over 99% of the subbituminous, and 97% of the anthracite coals. Fifteen percent of the coals are classified as medium-sulfur coals (1.1-3.0%), and 20% as high-sulfur coals (over 3.0%).

The latter two classes include 70% of the bituminous coals. Two-thirds of the high-sulfur coal is east of the Mississippi and comprises 43% of the total reserves in that section of the country.[10]

Sulfur occurs in coal in three forms: 1) combined with the organic coal substance, 2) combined with iron (pyritic), and 3) combined as sulfate.[3] Generally, organic sulfur predominates in low-sulfur coals. As total sulfur increases, both organic and pyritic forms increase. Sulfate sulfur in unweathered coals is usually less than 0.05%.

MANUFACTURE OF PIPELINE GAS

Conversion of coal to pipeline-quality gas by hydrogasification is shown in Figure 1, which is a simple block flow diagram giving basic steps in the process used. Ground, raw bituminous coal is pretreated by a mild air oxidation to prevent agglomeration during hydrogasification. Hydrogen is supplied by synthesis gas generated by the electrothermal gasification of hydrogasifier char. Hydrogasifier effluent is scrubbed to remove CO_2 and H_2S and then sent to methanation to produce 950 Btu/CF heating value gas. In reviewing the recovery of sulfur for this process we have considered two cases: a high-sulfur coal containing 4.4% sulfur, and a low-sulfur coal containing 1.5% sulfur. These cases are based on pipeline gas plant designs for two different Pittsburgh seam coals. For the pipeline gas production capacity of 250 billion Btu/day, used throughout this study, sulfur inputs are 739 and 199 tons/day for high- and low-sulfur coals. Table 1 summarizes the distribution of sulfur in the gasification process.

Table 1. DISTRIBUTION OF SULFUR IN HYDROGASIFICATION PROCESS

	Low-Sulfur Coal		High-Sulfur Coal	
	Tons Sulfur/ Stream-Day	%	Tons Sulfur/ Stream-Day	%
Raw Coal	199	100	739	100
As SO_2 in Pretreatment Off-Gas	30	15.1	166	22.5
In Pretreatment Fines	5	2.5	15	2.0
In H_2S From Hydrogasifier	158	79.4	487	65.9
Residue Char	6	3.0	71	9.6

During pretreatment about 15-25% of the sulfur is oxidized to SO_2. Most of the remaining sulfur is converted to H_2S during the hydrogasification of the pretreatment char. This includes virtually all organic and pyritic sulfur. Sulfur in the hydrogasifier char is essentially sulfide.

In this study we have considered sulfur recovery in two phases: 1) from H_2S only by the Claus Process, with SO_2 vented or scrubbed out of the gas without elemental sulfur recovery, and 2) from both H_2S and SO_2. Figures 2 and 3 show the distribution of sulfur for the first phase only. In high-sulfur coal there is a large amount of pyritic sulfur. The char from hydrogasification contains 1.7% sulfur, largely as sulfide sulfur. We have assumed one-half of this sulfur is gasified and returns to the hydrogasifier as H_2S in synthesis gas.

This is a conservative assumption; pilot plant data indicate even more sulfur will be gasified. For the low-sulfur case, the hydrogasifier char contains only 0.1% sulfur and is assumed to pass through the electrogasifier unchanged.

SULFUR RECOVERY FROM H_2S

Hydrogen sulfide feed to the Claus plant is contained in acid gas stripped from the scrubbing solutions in the purification section. Because of the large amount of CO_2 present, the H_2S concentration in this stream is low, 6 and 2% for the high- and low-sulfur coals. By modifying the scrubbing system to have two separate scrubbing liquid streams, it is possible to selectively recover 90% of the H_2S, while absorbing only 25% of the CO_2 in a short, "quick contact" section of the absorber. By this method, the H_2S concentrations in the sulfur recovery plant feed can be raised to 18.7 and 6%, respectively. Although the total amount of sulfur available is reduced, at higher H_2S concentrations costs per ton of recovered sulfur are greatly lowered. Also, the percentage sulfur recovered from the Claus plant feed is raised so that in the low-sulfur case overall recovery is somewhat higher.

Table 2 summarizes the economics for recovery of sulfur from the H_2S. Figure 4 gives a flow sheet representing the process scheme. Processing methods and costs for sulfur plants are based on published information and private communication with Pan American Petroleum Corp.[4, 9, 11]

Figure 4 shows the direct oxidation and split-flow processes used to produce sulfur from H_2S depending on the concentration of H_2S in the feed stream. Direct oxidation was used in all except the 18.73% /H_2S concentration stream case, where the split-flow process was used.

Generally, a two-reactor system is used for optimum sulfur recovery. The gases from first reactor are cooled for sulfur condensation, preheated, and sent to second reactor where additional sulfur is recovered.

After sulfur recovery from the second reactor, the gases go to an incinerator and are heated to 1200°F, where residual H_2S is converted to SO_2. If SO_2 from pretreatment off-gas is being recovered, the incinerator gases are cooled and sent to SO_2 extraction; otherwise, they are vented. Electrogasifier char is used as fuel for preheating the gases going to the reactor and for the incinerator.

Direct Oxidation Process

In this process air and the H_2S stream are preheated and passed over the catalyst beds for conversion to sulfur.

Split-Flow Process

In split flow, one-third of the H_2S, burned in a furnace boiler to produce SO_2, is combined with bypassed H_2S stream and is then passed over a catalyst bed to produce sulfur. The heat generated in burning H_2S is used to produce steam as a by-product.

Table 2. SUMMARY OF COSTS FOR RECOVERY OF SULFUR FROM H_2S IN HYDROGASIFIER EFFLUENT BY CLAUS PROCESS

	Coal Type, % Sulfur			
	Low-Sulfur Coal, 1.5		High-Sulfur Coal, 4.4	
Feed to Claus Plant	Purification Off-Gas	Concentrated Purification Gas	Purification Off-Gas	Concentrated Purification Gas
H_2S Concentration, mole %	2.03	6.95	6.0	18.7
Sulfur Recovery, %	70	86	85	91
Sulfur Recovery, tons/day	110	122	414	399
Sulfur Recovery, long tons/day	98.2	109	369.6	356
90% Stream Factor, long tons/year	32,260	35,810	121,410	116,950
INVESTMENT				
Claus Plant, $	3,400,000	1,200,000	4,200,000	1,700,000
Incinerator With Stack, $	300,000	300,000	300,000	300,000
Additional H_2S Concentration Investment, $	--	200,000	--	200,000
Total Fixed Investment, $	3,700,000	1,700,000	4,500,000	2,200,000
OPERATING COSTS				
Char Fuel, $4/ton, $	332,000	378,000	381,000	349,000
Power, $0.003/kWhr, $	30,000	32,000	37,000	39,000
Sulfur Loading Cost, 25¢/long ton, $	8,000	9,000	30,000	29,000
Labor, Maintenance, and Supplies, $	32,000	36,000	73,000	70,000
Steam By-Product, 25¢/1000 lb, $	--	--	--	− 99,000
Subtotal, $	402,000	455,000	521,000	388,000
Capital Charges, Includes 5% Depreciation, $	385,000	130,000	499,000	203,000
Sulfur Recovery Charge, $/yr	787,000	585,000	1,020,000	591,000
Sulfur Recovery Charge, $/long ton	24.4	16.3	8.4	5.1

Table 2, Cont. SUMMARY OF COSTS FOR RECOVERY OF SULFUR FROM H_2S HYDROGASIFIER EFFLUENT BY CLAUS PROCESS

	Coal Type, % Sulfur											
	Low-Sulfur Coal, 1.5						High-Sulfur Coal, 4.4					
Feed Claus Plant	Purification Off-Gas			Concentrated Purification Gas			Purification Off-Gas			Concentrated Purification Gas		
Sulfur Sale Price, \$/long ton	20	30	40	20	30	40	20	30	40	20	30	40
Annual By-Product Revenue, \$1000	−141.9	180.6	503.2	132.5	490.5	848.6	1408.4	2622.5	3836.7	1742.5	2912.0	4081.4
Decrease in Gas Price, ¢/10^6 Btu	−0.17	0.21	0.59	0.16	0.58	1.0	1.66	3.09	4.53	2.06	3.44	4.82
20-yr Avg Price of Gas, ¢/10^6 Btu	53.2	52.8	52.4	52.8	52.4	52.0	51.3	49.9	48.5	50.9	49.6	48.2

Three out of the four cases in Table 2 have lean acid-gas feed, 2 to 6% H_2S, and make use of the direct oxidation process. In the fourth case, 18.7% H_2S, the split-flow process is used. Raising the percentage of H_2S greatly reduces sulfur recovery plant investment for a given capacity, particularly in the range from 2 to 20%.

Economics of Sulfur Recovery From H_2S

Sulfur recovery ranges from 98 to 370 long tons/day for 1.5 and 4.4% sulfur in the coal. Recovery costs, with capital charges based on utility-type financing, vary from \$24 to \$5.1/ton as a break-even cost (Table 2). Capital charges are treated the same as for the pipeline-gas-from-coal plant except there is no return on investment or income tax. The cost is enough to cover operating and capital charges so the price of pipeline gas is the same as if there were no sulfur: 53¢/million Btu. Financing is 65% debt and 35% equity, depreciation is 5%/yr, and the interest rate is 5% on outstanding debt. Costs are summarized in Table 2.

The effect of the sulfur by-product on the price of pipeline gases is shown graphically in Figures 5 and 6. The base price of pipeline gas is 53¢/million Btu with no elemental sulfur recovery. Because of the higher unit cost of recovery and the small amount of sulfur obtained from low-sulfur coal, the effect of sulfur recovery on gas price is slight: 1¢ or less per million Btu. With high-sulfur coal the effect is much more significant, ranging from just under 2¢ to over 4.5¢/million Btu as sulfur market price increases from \$20 to \$40/ton. Raising the percentage H_2S in the feed has a significant effect on the cost per ton of sulfur, but only a small effect on the price of pipeline gas. A change of \$1 million in investment for a 250 billion Btu/day plant, representing 25-50% of the cost of the sulfur recovery section, will change the price of pipeline gas by about 0.25¢/million Btu.

SULFUR RECOVERY FROM SO_2 AND H_2S

Recovery of sulfur from H_2S still leaves substantial amounts of SO_2 vented to the atmosphere from the coal pretreatment and sulfur plant incinerator off-gases. For high-sulfur coal the total is 239.3 to 254.3 tons/day of sulfur depending on whether the H_2S concentration in the feed to the sulfur recovery plant is raised by modifications in the pipeline gas purification section. This is one-third of the sulfur entering the plant with the coal. The effluent SO_2 concentration is about 0.6%. For the low-sulfur coal, 66-78 tons/day of sulfur as SO_2 is vented, with an average concentration of about 0.3%. These SO_2 concentrations are similar to those in power plant flue gases; therefore, techniques applicable for SO_2 removal from power plant flue gases should be applicable to flue gases from pipeline-gas-from-coal plants.

A large number of processes are in various stages of development at present. Review of these is beyond the scope of this study. The SO_2 can be removed and discarded in chemical combination with limestone as in the Combustion Engineering Process,[1] extracted and liquefied as in the Wellman-Lord Process,[1, 16, 17] converted to sulfuric acid as in the Monsanto Cat-Ox Process,[1, 6] or converted to elemental sulfur as in the Alkalized Alumina Process.[6]

SO_2 Removal

For removal of SO_2 from pretreatment and incinerator off-gases in our system without elemental sulfur recovery we have considered removal by the alkali-injection, wet-scrubbing process. Although definitive costs are not available, published data indicate a range of costs.[1,8,18] We have assumed an average price of $10/ton of SO_2. Since no additional sulfur is produced, the cost of removal must be added to the price of the pipeline gas without credit for by-products. For the low-sulfur coal the additional cost is about 0.5¢/million Btu; for high-sulfur coal, it is 1.7¢/million Btu. These added costs are indicated in Figures 5 and 6. The sensitivity is such that, for each $1/ton change in SO_2 removal cost, the effect on pipeline gas price is 0.05¢ and 0.17¢/million Btu for low- and high-sulfur coals.

As a result of the additional costs for SO_2 removal, for low-sulfur coal the price of by-product sulfur will have to be about $35/long ton to balance the costs of desulfurization (Figure 5). However, even with sulfur at $20/ton, the penalty is only about 0.5¢/million Btu of pipeline gas. For a plant using high-sulfur coal, as long as by-product sulfur sells for $20/ton or higher, pipeline gas price will not be penalized by costs of desulfurization (Figure 6).

Although current prices for sulfur are at the $40/long ton level, future prices, with adequate or oversupply, could depress the price to $30 or less. Since pipeline-gas-from-coal plants will operate in the future, we have considered $40/long ton as a conservative maximum in a range of $20-$40/long ton.

In a pipeline-gas-from-coal plant, the production of large amounts of H_2S during hydrogasification brings an advantage in sulfur recovery from SO_2 that is not present in a power plant. The SO_2 extracted from the pipeline gas plant "flue" gases can be sent to the sulfur recovery plant and reacted with H_2S extracted from the hydrogasifier effluent according to the Claus reaction:

$$SO_2 + 2H_2S \rightarrow 2H_2O + 3S$$

Less combustion of H_2S is required to maintain the required H_2S/SO_2 ratio of about 2. This may require more fuel, but it eliminates the need for separate reduction of SO_2 to recover the sulfur. A recent announcement briefly describes a process in which sulfur is produced by catalytic reaction of H_2S and SO_2. Some of the SO_2 reacts with methane to make more H_2S. A pipeline gas plant already has the necessary H_2S.[12]

Published information on the Wellman-Lord Process shows production of liquid SO_2. In this process, SO_2 is removed by scrubbing the flue gas with a solution of potassium sulfite precipitated as potassium pyrosulfite. The crystals are recovered and dissolved in water, and SO_2 is stripped out with steam. Then the steam is condensed and the SO_2 is compressed and liquefied.

SO_2 Recovery

For our application we would not need to liquefy the SO_2. Based on published costs for the process[16,17] and the pipeline gas capital charges described above, the cost of SO_2 extraction for our application might range from $11 to $15/ton of SO_2. Contact with Wellman-Lord indicated that extraction of SO_2 in the pretreatment off-gas and in the sulfur recovery plant incinerator flue gas.

could be feasible and could be simpler than in a proposed power plant system making pure liquid SO_2. Although we do not have a specific design for our system, it appears that an SO_2 extraction cost of $10 to $15/ton is a representative range for this process application.

We have made preliminary estimates of the cost of SO_2 extraction based on published costs for the alkalized alumina process.[5,6] This process requires the generation of a producer gas to regenerate the absorbent, producing H_2S which is then fed to the Claus plant to yield elemental sulfur. Published investment costs were adjusted to our capacities. Incremental SO_2 removal costs ranged from $25/ton for the high-sulfur coal to over $50/ton for the low-sulfur coal. Since the high H_2S/SO_2 ratio produced in the pipeline gas plant makes reduction of SO_2 unnecessary, this process would be at the high end of the cost range for SO_2 extraction in our application.

Figures 7 and 8 show the flows of sulfur through the pipeline gas and desulfurization systems for the 1.5 and 4.4% sulfur coals. Numbers are in tons/day. In these systems, sulfur is obtained from SO_2 as well as H_2S. Flue gas from pretreatment and from the sulfur plant incinerator goes to SO_2 extraction where 90% of the SO_2 is recovered and sent to the Claus unit. With this system, the concentrated H_2S stream is obtained from pipeline gas purification. This reduces the cost of the H_2S recovery. Unrecovered H_2S is burned and recycled as SO_2. Sulfur recovery is increased from 110 to 160 long tons/day for low-sulfur coal, and from 370 to 532 long tons/day for high-sulfur coal. With high-sulfur coal the amount of SO_2 extracted exceeds one-half the H_2S, so a small amount is liquefied.

Costs for Sulfur Recovery From H_2S and SO_2

Table 3 summarizes costs of sulfur recovery for combined SO_2 extraction and Claus plant operation; results are depicted graphically in Figures 9 and 10. Variables are the cost of SO_2 extraction and the sale price for sulfur at the pipeline gas plant.

For low-sulfur coal (Figure 9) desulfurization improves the price of gas slightly, about 0.5¢/million Btu, if sulfur can be sold at $30/ton. If sulfur from SO_2 is not recovered but SO_2 is scrubbed out and only the sulfur from H_2S is recovered (Figure 5), sulfur credits just about balance the costs for desulfurization.

With high-sulfur coal the effects are much greater because there is over 3 times as much sulfur recovered. Sulfur recovery substantially lowers the price of gas if the sulfur price is $25/ton or better. At a sulfur price of $30/ton or better and an SO_2 extraction cost of $15/ton, the price of gas is lowered by 3¢-5¢/million Btu. If SO_2 is removed and only sulfur from H_2S recovered, then the price is about 51.5¢/million Btu. Even at $20/ton and full desulfurization, recovery of sulfur from H_2S and SO_2 has an advantage of 1¢ over the alternative. This is because, even though it costs $15/ton SO_2 ($30/ton sulfur) to extract SO_2 for sulfur recovery and $10/ton ($20/ton sulfur) to remove it as $CaSO_4$, the sulfur recovered more than pays for this differential cost of sulfur removal. The price of sulfur would have to drop to well below $20/ton before it is less economical to recover it than to remove and discard it.

Table 3. SUMMARY OF COSTS FOR RECOVERY OF SULFUR FROM H_2S IN HYDROGASIFIER EFFLUENT AND SO_2 IN PRETREATMENT AND INCINERATOR OFF-GASES BY SO_2 EXTRACTION AND CLAUS PROCESS

	Coal Type, % Sulfur	
	Low-Sulfur Coal, 1.5	High-Sulfur Coal, 4.4
Feed to Claus Plant	H_2S From Concentrated Purification Off-Gas; SO_2 From Extraction Plant	H_2S From Concentrated Purification Off-Gas; SO_2 From Extraction Plant
SO_2 to Extraction Unit, mole %	0.3	0.9
Equivalent SO_2 + H_2S Feed, mole %	9.5	23.7
Sulfur Recovery, %	88	91
Sulfur Recovery, tons/day	181	596
Sulfur Recovery, long tons/day	161.6	532
90% Stream Factor, long tons/yr	53,090	174,760
INVESTMENT		
Claus Plant, $	1,200,000	2,500,000
Incinerator, $	300,000	300,000
Additional H_2S Concentrator Investment, $	200,000	200,000
Heat Exchange Incinerator Feed and Effluent, $	1,700,000	1,700,000
Total Fixed Investment, $	3,400,000	4,700,000
OPERATING COSTS		
Char Fuel, $4/ton, $	140,000	54,000
Power, $0.003/kWhr, $	9,000	7,000
Cooling Water, $0.10/1000 gal, $	5,000	5,000
Loading Cost, 25¢/long ton, $	13,000	44,000
Labor, Maintenance, and Supplies, $	43,000	73,000
Subtotal, $	210,000	183,000
Capital Charges	353,000	528,000
Depreciation at 5%, Revenue Required, $	563,000	711,000

Table 3, Cont. SUMMARY OF COSTS FOR RECOVERY OF SULFUR FROM H_2S IN HYDROGASIFIER EFFLUENT AND SO_2 IN PRETREATMENT AND INCINERATOR OFF-GASES BY SO_2 EXTRACTION AND CLAUS PROCESS

	Coal Type, % Sulfur					
	Low-Sulfur Coal, 1.5			High-Sulfur Coal, 4.4		
Feed to Claus Plant	H_2S From Concentrated Purification Off-Gas, SO_2 From Extraction Plant			H_2S From Concentrated Purification Off-Gas, SO_2 From Extraction Plant		
SO_2 EXTRACTION						
Sulfur Sale Price, $/long ton	20	30.	40	20	30	40
SO_2 Extraction, $10/ton, $		417,200			1,440,100	
Annual Total Sulfur Recovery Cost, $		980,200			2,151,100	
Annual By-Product Revenue, $	84,940	615,800	1,146,700	1,345,700	3,093,300	4,840,900
Decrease in Gas Price, ¢/10^6 Btu	0.1	0.73	1.35	1.58	3.64	5.71
Price of Gas, ¢/10^6 Btu	52.9	52.27	51.65	51.42	49.36	47.29
SO_2 Extraction at $15/ton, $		625,800			2,160,200	
Annual Total Sulfur Recovery Cost, $		1,188,800			2,871,200	
Annual By-Product Revenue, $	−127,400	403,400	934,300	800,400	2,548,000	4,295,600
Decrease in Gas Price, ¢/10^6 Btu	−0.15	0.48	1.1	0.94	3.01	5.07
Price of Gas, ¢/10^6 Btu	53.15	52.5	51.9	52.1	50.0	47.9
SO_2 Extraction at $30/ton, $		1,251,600			4,320,400	
Annual Total Sulfur Recovery Cost, $		1,814,600			5,031,400	
Annual By-Product Revenue, $	−753,800	−223,000	307,900	1,537,900	209,700	1,957,300
Decrease in Gas Price, ¢/10^6 Btu	−0.89	−0.26	0.36	−1.81	0.25	2.31
Price of Gas, ¢/10^6 Btu	53.9	53.3	52.64	54.8	52.75	50.7

The above applies, however, only to the situation where the SO_2 is not released to the atmosphere. If SO_2 can be vented, then there is not much economic advantage in recovering that sulfur which is converted to SO_2 in the process. If air pollution standards require SO_2 removal, then it appears more economical to recover it as sulfur than as sulfate.

In the manufacture of pipeline gas from coal by hydrogasification, high-sulfur coal is more of an asset than a liability. The production of H_2S facilitates sulfur recovery from both SO_2 and H_2S and has the potential of reducing gas price by several ¢/million Btu. Hydrogen consumed in making H_2S is only 0.75¢/million Btu. Viewed as a source of sulfur, high-sulfur coal is a higher grade raw material for gasification, and the costs of desulfurization in a gas plant based on this coal will yield a greater return than with low-sulfur coal.

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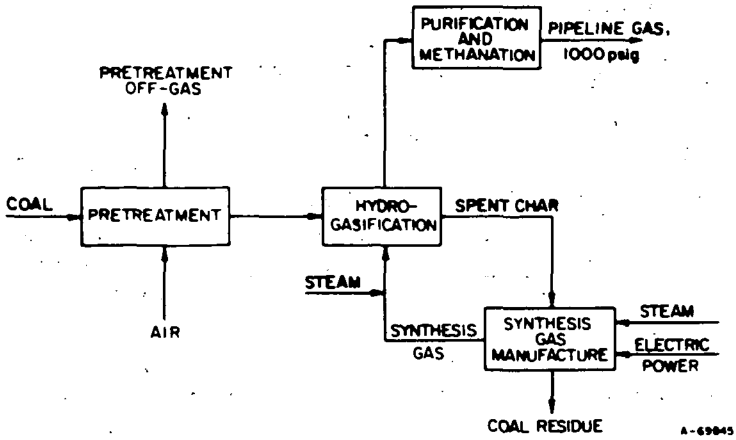

Figure 1. PIPELINE GAS BY HYDROGASIFICATION OF BITUMINOUS COAL

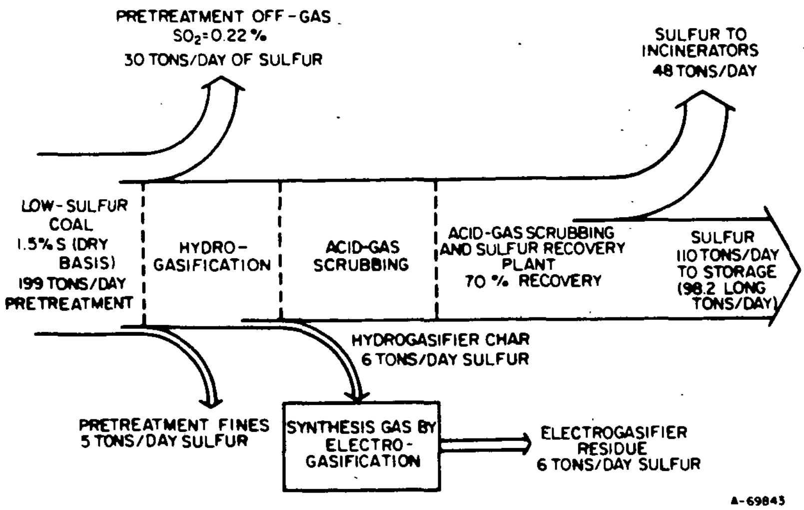

Figure 2. DISTRIBUTION OF SULFUR IN PIPELINE GAS PLANT FOR LOW-SULFUR COAL WITH NO SO_2 RECOVERY

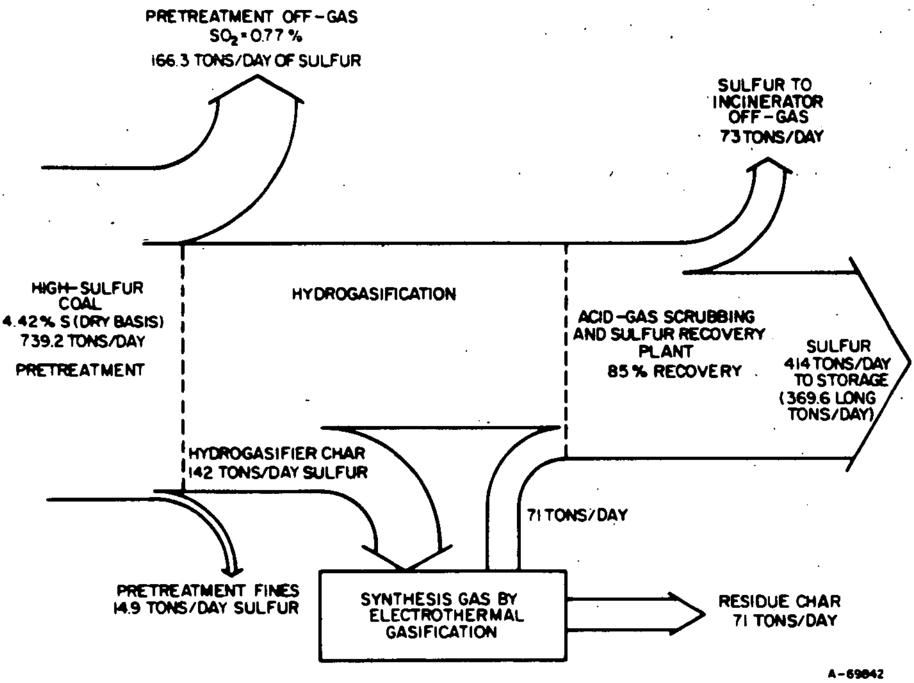

Figure 3. DISTRIBUTION OF SULFUR IN PIPELINE GAS PLANT FOR HIGH-SULFUR COAL WITH NO SO_2 RECOVERY

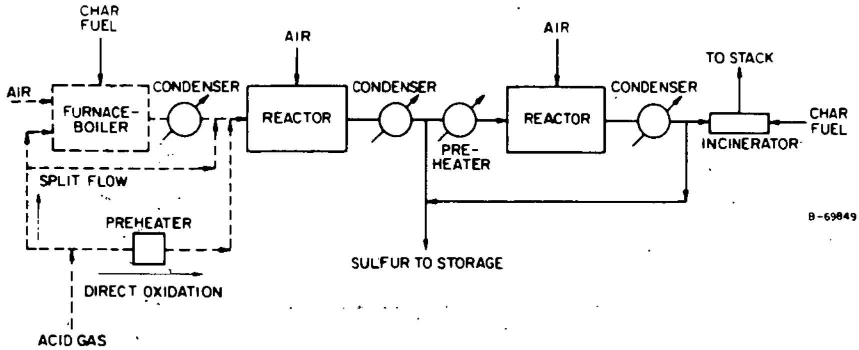

Figure 4. SULFUR RECOVERY SYSTEM

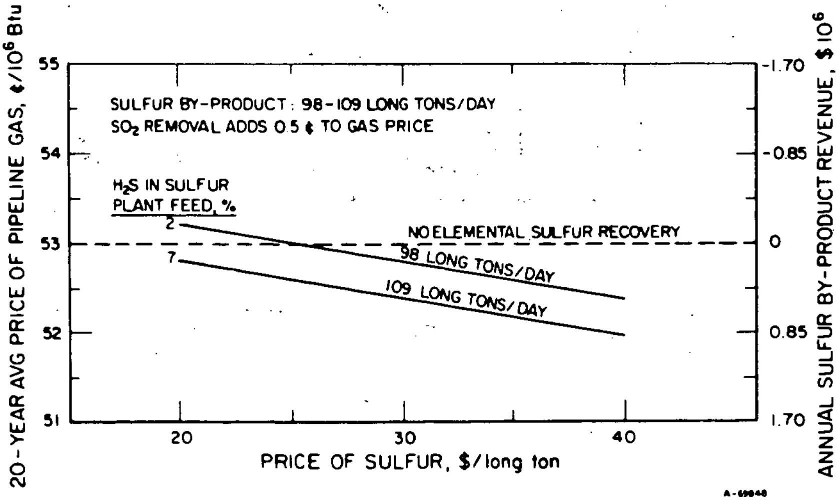

Figure 5. EFFECT OF SULFUR RECOVERY FROM H_2S ON PRICE OF PIPELINE GAS FOR 1.5% SULFUR COAL

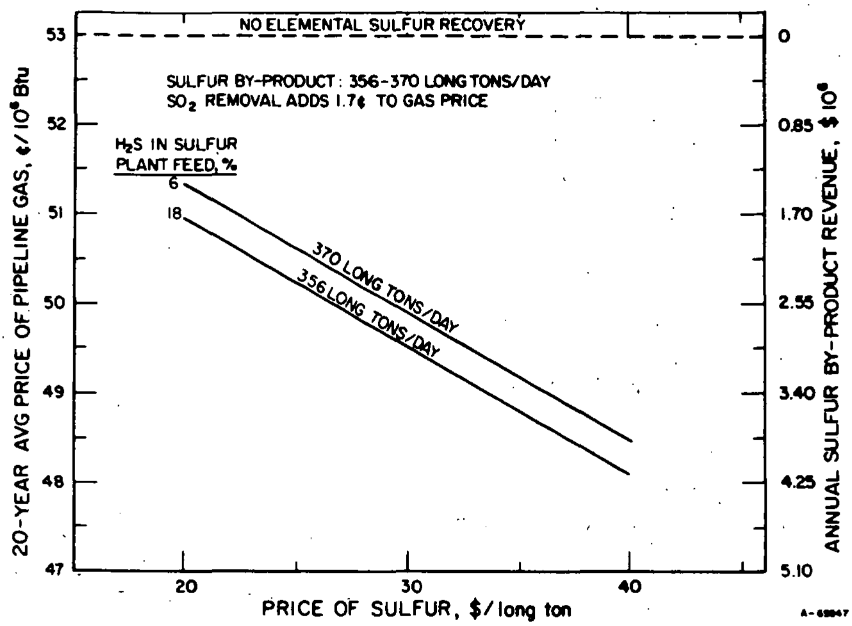

Figure 6. EFFECT OF SULFUR RECOVERY FROM H_2S ON PRICE OF PIPELINE GAS FOR 4.4% SULFUR COAL

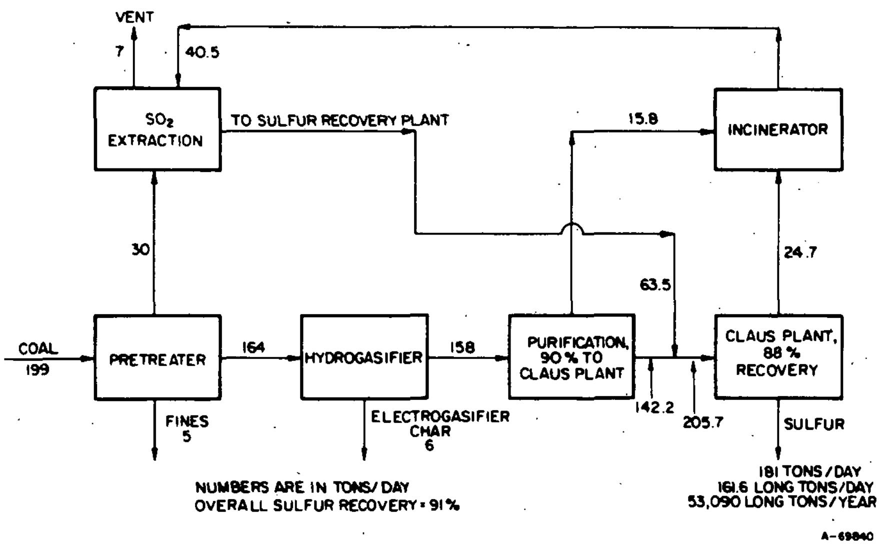

Figure 7. FLOW OF SULFUR IN PIPELINE GAS PLANT USING LOW-SULFUR COAL WITH SO_2 REMOVAL FROM PRETREATER AND INCINERATOR OFF-GAS

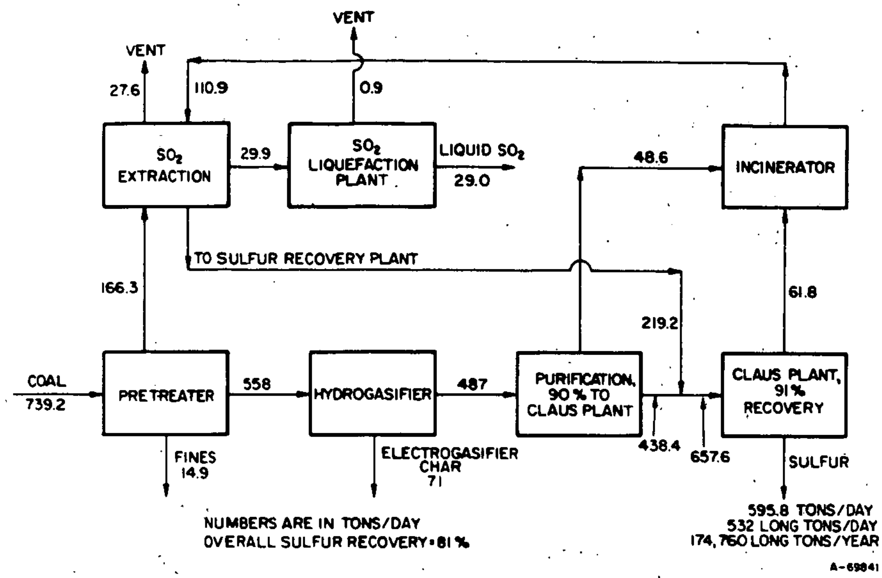

Figure 8. FLOW OF SULFUR IN PIPELINE GAS PLANT USING HIGH-SULFUR COAL WITH SO_2 RECOVERY FROM PRETREATER AND INCINERATOR OFF-GAS

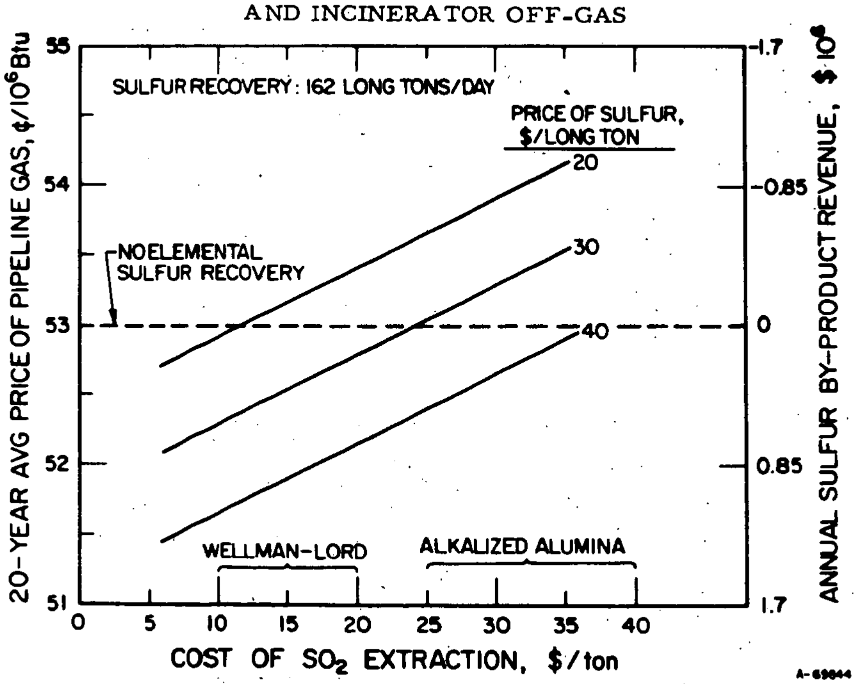

Figure 9. EFFECT OF COST OF SO_2 EXTRACTION AND SULFUR RECOVERY ON PRICE OF PIPELINE GAS USING 1.5% SULFUR COAL

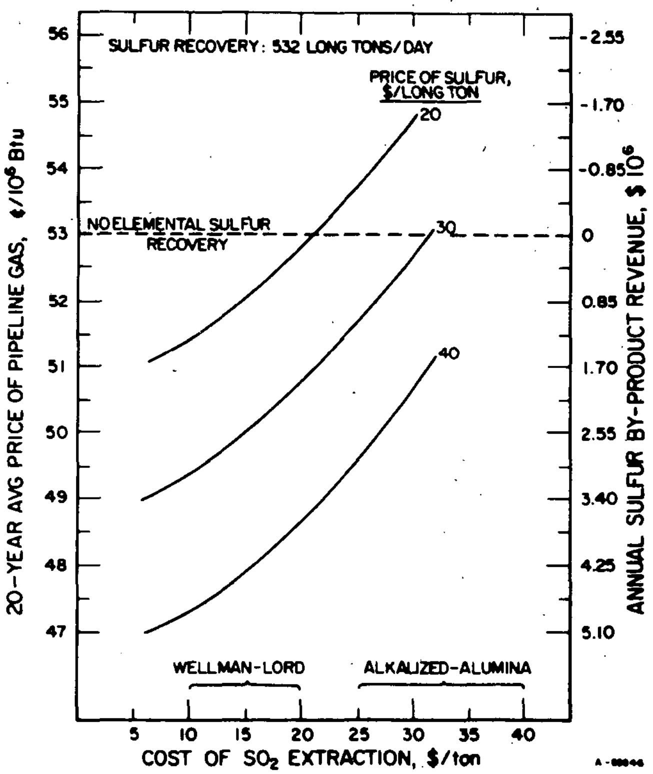

Figure 10. EFFECT OF COST OF SO_2 EXTRACTION AND SULFUR RECOVERY ON PRICE OF PIPELINE GAS USING 4.4% SULFUR COAL